HATCHES HARBOR TIDAL RESTORATION MONITORING REPORT 2008

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BACKGROUND

Hatches Harbor is a 200-acre salt marsh that was bisected in 1930 by a dike originally built to reduce population levels of nuisance mosquitoes. From 1930 to 1987, tidal exchange of saline waters was essentially eliminated, which caused hydrological and geochemical changes that severely impacted the natural system. In 1987, the one-way flap valve in the original 2-ft diameter culvert was removed during repair work following storm damage to the dike. Although tidal exchange was appreciably increased, it was not enough to stop continued degradation of the restricted marsh.

In 1996, the National Park Service, in cooperation with the Provincetown Airport Commission, Provincetown Municipal Airport and the Federal Aviation Administration, agreed to restore the degraded habitat. The restoration was initiated constructing four 7-foot wide rectangular box culverts with adjustable gates to regulate tidal flow (see Figure 1). Since April 1999, these culverts were progressively opened until October 2005, at which point full tidal-exchange capacity was reached.

A comprehensive environmental monitoring program was begun in 1997, prior to construction of the new culverts, and continues to the present. The main goal of the monitoring program is to document the pace of restoration by comparing tide heights, water quality, vegetation, and estuarine fauna above and below the Hatches Harbor Dike. For further background on the Hatches Harbor restoration project, please refer to Portnoy et al. (2003).

This report is an annual update to the most recent reports on the Hatches Harbor restoration project that summarizes 2006 and 2007 data (Gwilliam et al. 2007; Smith et al. 2008; Smith et al., in press). Other information, including previous reports, can be found at:

http://www.nps.gov/caco/naturescience/hatches-harbor-tidal-restoration-project.htm

I. TIDE HEIGHTS, SALINITIES, AND VEGETATION

Stephen Smith and Kelly Chapman

Methods

Methods of data collection followed prior procedures and are briefly outlined below. For further details on protocols, please refer to previous reports, including Smith et al. (2008) and Smith et al. (in press).

Tide heights

HOBO water level loggers were deployed just upstream and downstream of the dike within the main tidal channel (Figure 1). The specific locations were the same as in past monitoring. All units were surveyed in relation to known elevations (benchmarks) and all data were corrected for barometric pressure. In the past, water levels were also monitored at a third site near the Provincetown airport. Hydrologic monitoring since 2005, when the culverts were fully opened, has provided an adequate quantity of data to show that tides there do not exceed levels that would threaten airport operations. As such, no instrumentation was deployed in this area in 2008.

Porewater salinities

As in previous surveys, porewater samples at each permanent plot were extracted from a depth of ~ 10 cm and salinities measured with a refractometer. Sampling of all plots was done during a single day at low tide (Oct 31, 2008).

Vegetation

All vegetation plots in the restricted marsh (n=106) were surveyed in 2008. Visual estimates of cover class categories were based on a modified Braun-Blanquet scale where 0=0, >0-1%=1, >1-5%=2, 6-10%=3, 11-25%=4, 26-50%=5, 51-75%=6, 76-100%=7). In addition to assessments of cover, *Phragmites australis* (hereafter refereed to as *Phragmites*) maximum stem heights and stem densities (all stems within 1m^2 or 0.25m^2 subplot) were determined in October. *Phragmites* biomass was then estimated based on the equations of Thursby et al. (2002). In October, porewater salinities were measured in each plot in samples taken from a depth of ~10 cm. Since the unrestricted side of the marsh has remained stable over the last decade (Smith et al., in press), only the restricted area was analyzed and discussed below.

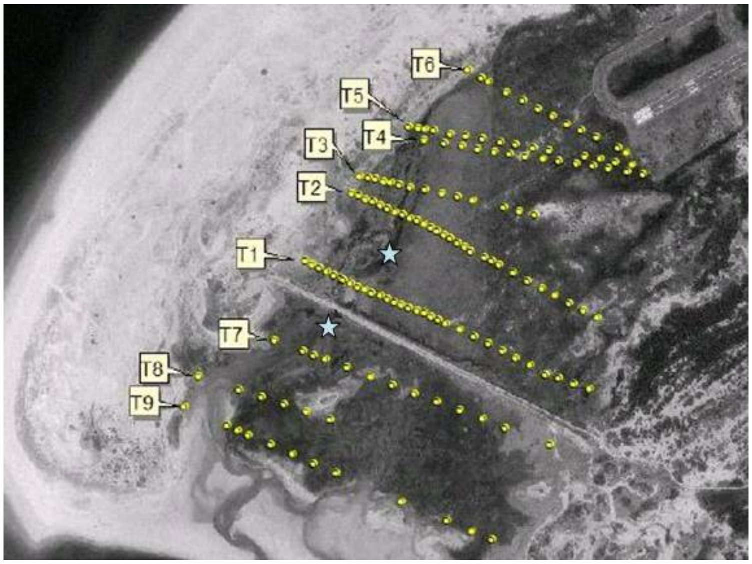

Figure 1. Map of Hatches Harbor permanent vegetation plots along the transects established in Hatches Harbor (stars indicate position of water level loggers).

In 2008, *Phragmites* biomass was estimated in a slightly different manner. In previous years, stem heights and stem densities were used in a regression equation adapted from Thursby et al. (2001) to generate a value for biomass. However, analysis of *Phragmites* data from 2002, 2004, 2006, and 2007 showed that values generated by using maximum stem height (i.e., the height of the tallest stem in the plot) and stem density (number of all stems in the plot) in the regression equation for biomass were very closely correlated with those using all stem heights and stem density (R^2=0.92) (Figure 2). In other words, maximum stem height and stem density were very good predictor variables for biomass. This is similar to Thursby et al (2001), who reported that measurements of the five tallest stems were sufficient to predict biomass with a high degree of accuracy. As such, only maximum stem heights were recorded in 2008, which resulted in a considerable savings in time and effort in the field.

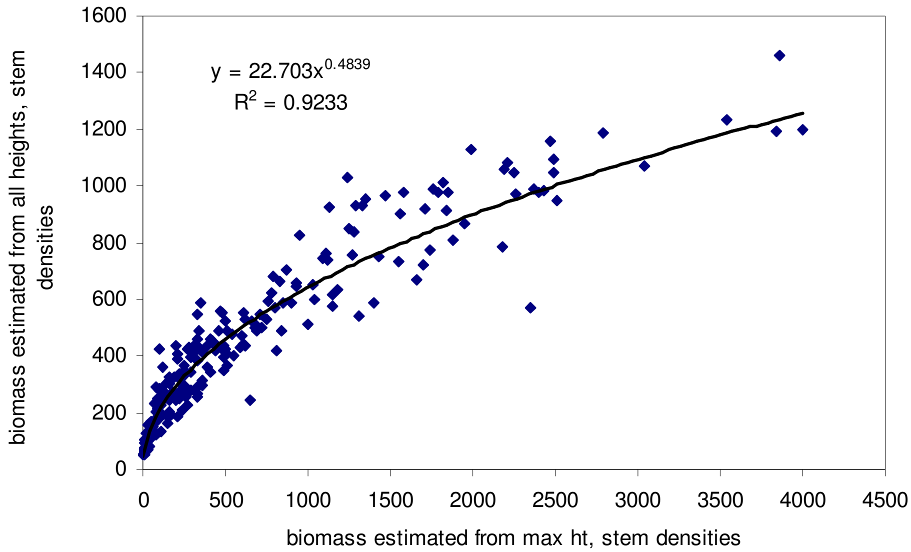

Figure 2. Correlation between *Phragmites* biomass estimated using all stem heights vs. maximum stem height within plots (data are from 2002-2007).

Plant cover data were portrayed using multidimensional scaling (MDS) based on a Bray-Curtis similarity index of raw cover scores. Differences in plant communities between years or area of marsh (unrestricted vs. restricted) were tested by Analysis of Similarities (ANOSIM; Primer ver. 5). Univariate data were tested by Analysis of Variance (ANOVA).

Results

Tide heights

The tidal regime on both sides of the dike in 2008 remained very similar to that recorded in 2007 during the same period (Table 1). For the restricted marsh, this is not unexpected since the physical dimensions of the culvert openings have not changed since 2005. As it stands, the tidal range just upstream of the dike, within the main creek, is 57% of that on the unrestricted side of the marsh.

Table 1. Tide height summary for the restricted and unrestricted marsh areas (2007 vs. 2008).

		High	Low	Range	% UR
Aug08 –Oct08	R	1.13	0.43	0.70	57
Aug08 –Oct08	UR	1.48	0.24	1.24	
Aug07 –Oct07	R	1.50	0.82	0.68	57
Aug07 –Oct07	UR	1.81	0.60	1.21	

Porewater Salinities

In general, there has been a considerable increase in the extent of marsh experiencing intermediate salinities over the past few years. The number of plots with salinities between 10 and 25 has increased steadily since 2004 (Table 2). Plots with salinities > 25 ppt increased between 2004 and 2006, but have remained about the same for the past 2 years. Since the culvert gates were fully opened in 2005, salinities have shown the most change along transects 4-6, where saltwater now penetrates much further upslope (Figure 3). One important note about salinities: these data represent single sampling events for each year. In reality, porewater salinity levels fluctuate with the tidal cycle, precipitation, and distance from the main tidal creek. Thus, while the general spatial trends may be accurate, the absolute values may be somewhat different from longer-term, “average” conditions. That said, all sampling in all years was done at similar times during the season (Sept-Oct) and tidal cycle (immediately after Spring high tides).

Table 2. Mean salinities by year and number of plots with salinities that fall into selected ranges.

	2004	2006	2007	2008
means	20.5	24.6	27.4	27.6
# plots > 25	54	61	68	66
# plots > 20	58	68	77	79
# plots > 15	60	72	80	84
# plots > 10	62	78	84	86

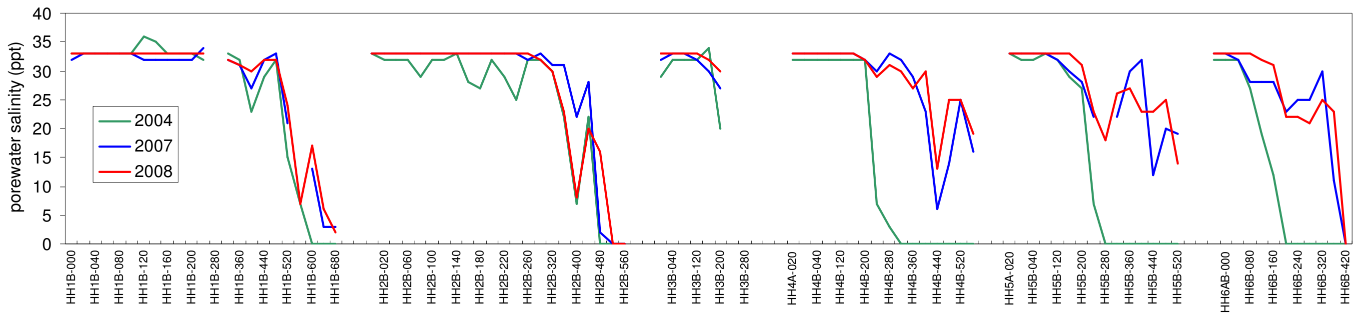

Figure 3. September porewater salinities (10-cm depth) by plot in 2004 (prior to the last gate openings in 2005 that permitted maximum exchange), 2007, and 2008.

Vegetation

While very large changes have occurred since the onset of restoration in 1998 (Smith et al., in press), ANOSIM suggested that overall plant community composition (based on cover class scores) was not significantly different in 2008 compared with 2006 (p=0.23, Global R: 0.003). Notwithstanding, a number of important changes in individual species and individual plots have occurred during this time period (Table 3). Salt-intolerant taxa continue to decline across the restricted floodplain, including the highly invasive *Lythrum salicaria* (purple loosestrife). In fact, the total number of species in the restricted floodplain decreased from 43 to 32 during the past 2 years. With the exception of *Distichlis spicata*, all native halophyte species increased % cover and frequency. *Phragmites* cover and frequency decreased slightly between years. However, it was primarily changes in the spatial distribution of *Phragmites*, *S. alterniflora*, and *S. patens* and the abundance of *Morella pensylvanica* that accounted for the shifting patterns in ordinal space between 2006 and 2008 (Figure 4). In general, *Phragmites* continues to migrate upslope with establishment of *S. alterniflora* and *S. patens* in its wake. *Phragmites* is invading areas recently made "open" by salt-induced mortality of shrubs and freshwater graminoids there.

Table 3. Summed cover class values and frequency of all taxa in the restricted marsh in 2006 vs. 2008. Native salt marsh halophyte species and important exotics (*Phragmites australis* and *Lythrum salicaria*) are highlighted.

	sum cover		freq	
	2006	2008	2006	2008
Achillea millefolium	1	6	0.9%	0.9%
Agrostis stolonifera	1	0	0.9%	0.0%
Ammophila breviligulata	14	8	2.8%	2.8%
Aster novi-belgii	13	0	9.2%	0.0%
Atriplex hastata	10	0	4.6%	0.0%
Carex sp.	9	13	4.6%	3.7%
Deschampsia flexuosa	24	24	5.5%	4.6%
Distichlis spicata	35	19	6.4%	4.6%
Eleocharis tenuis	3	0	0.9%	0.0%
Eupatorium dubium	1	0	0.9%	0.0%
Euthamia graminifolia	25	6	10.1%	1.8%
Holcus lanatus	9	0	3.7%	0.0%
Ilex verticillata	8	0	2.8%	0.0%
Juncus canadensis	3	4	1.8%	0.9%
Juncus effusus	10	5	4.6%	1.8%
Limonium carolinianum	7	22	3.7%	9.2%
Lythrum salicaria	14	4	5.5%	0.9%
Morella pensylvanica	39	30	8.3%	6.4%
Onoclea sensibilis	1	0	0.9%	0.0%
Osmunda regalis	7	0	2.8%	0.0%
Phragmites australis	289	286	54.1%	47.7%
Polygonella articulata	2	0	0.9%	0.0%
Prunus maritima	5	0	0.9%	0.0%
Prunus serotina	11	11	1.8%	1.8%
Puccinellia maritima	0	2	0.0%	0.9%
Rhus copallinum	3	2	1.8%	0.9%
Rosa carolina	12	9	3.7%	2.8%
Rubus flagellaris	11	5	3.7%	0.9%
Rubus hispidus	8	5	1.8%	0.9%
Rumex acetosella	2	3	0.9%	0.9%
Salicornia sp.	105	130	18.3%	33.0%
Scirpus cyperinus	5	0	1.8%	0.0%
Scirpus pungens	21	14	4.6%	2.8%
Solidago sempervirens	7	12	1.8%	3.7%
Solidago sp.	7	6	1.8%	1.8%
Spartina alterniflora	127	137	28.4%	33.9%
Spartina patens	76	84	15.6%	19.3%
Spergularia salina	0	8	0.0%	4.6%
Spiraea alba	7	5	3.7%	0.9%
Suaeda sp.	35	35	12.8%	19.3%
Thelypteris palustris	16	0	4.6%	0.0%
Toxicodendron radicans	15	10	3.7%	1.8%
Triadenum virginicum	5	0	3.7%	0.0%
Vaccinium corymbosum	4	0	0.9%	0.0%
Vaccinium macrocarpon	18	8	5.5%	1.8%

From the standpoint of individual transects, T1 and T2 exhibited the least movement in ordinal space between 2006 and 2008. These transects are closest to the point of seawater entry into the restricted marsh and show fewer changes now because they responded very early on in the restoration process. Now it is the transects further away from the dike (T3-T6) that are showing the most change. These changes appear to be the result of changes in seed dispersal and hydrology as barriers surface water flow disappear (Smith 2007). Some changes appear to be the result of tidal creek restoration that occurred in 2004, which allowed seawater to penetrate further into the marsh.

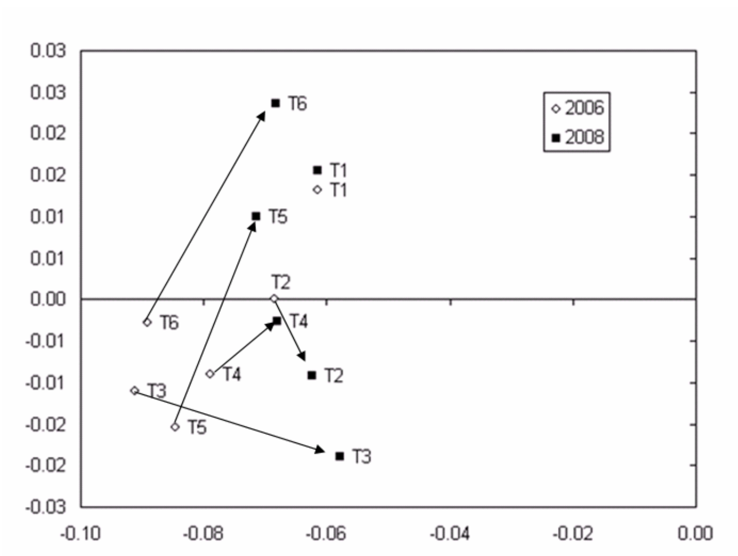

Figure 4. MDS of cover class data (only centroids depicted) in 2006 (open circles) to 2008 (solid squares). Arrows denote extent of movement in ordinal space between the two survey years.

With respect to trends in key species, the number of plots with *S. alterniflora* (the most dominant species of normally-functioning salt marshes in Cape Cod) has increased steadily since 1997 (Table 4). *S. patens* has also increased, although not as much due to the fact that this species does not tolerate flooding as well as *S. alterniflora*. Thus, while *S. patens* is expanding landward it is also being replaced by *S. alterniflora* along its seaward edge (lower elevations). These trends in expansion are shown in Table 5. *S. alterniflora* has expanded large distances landward along transects 2 and 3 in particular between 2006 and 2008.

Table 4. Number of plots with *S. alterniflora* by year.

1997	2002	2004	2006	2008
10	11	17	32	37

Table 5. Furthest distance away (upslope) from the main tidal creek that *S. alterniflora* has been recorded (the "1" values represent presence in creekbank plots).

	1997	2000	2002	2004	2006	2008	Total distance upslope
TR1	1	1	1	140	260	260	260
TR2	1	1	1	40	60	200	200
TR3	1	1	1	40	80	200	200
TR4	1	1	1	80	80	80	80
TR5	1	1	1	40	80	160	160
TR6	1	1	1	1	1	40	40

In contrast to *S. alterniflora*, the abundance of *S. patens* has not exhibited a clear trend in abundance over time. In fact, there has been relatively little change in the frequency of this species (Table 6). However, a plausible explanation exists for this finding. Because the amount of salt water flow was increased incrementally from 1997 to 2005, *S. patens* that become established at lower elevations are now being out-competed by *S. alterniflora*. However, *S. patens* should continue to expand into zones of higher elevations. To a certain extent, the establishment of *S. patens* in suitable "high marsh" areas has been limited by the presence of *Phragmites* (both live and dead) acting as a physical barrier to colonization and seed dispersal. Nevertheless, *S. patens* continues to appear in plots further and further away from the main tidal creek every year (Table 7).

Table 6. Number of plots with *S. patens* by year.

1997	2002	2004	2006	2008
15	14	20	17	20

Table 7. Furthest distance upslope (m) from main tidal creek that *S. patens* has been recorded.

	1997	2000	2002	2004	2006	2008	Total distance upslope (m)
tr1	40	40	60	60	60	280	240
tr2	-	-	20	60	80	260	260
tr3	-	1	-	80	80	-	80 (now replaced by *S. alterniflora*)
tr4	160	160	160	240	240	240	80
tr5	200	no data	200	240	240	240	40
tr6	-	1	40	40	40	40	40

Halophytic annual forbs belonging to the genera *Salicornia* and *Suaeda* have also exhibited significant expansion across the marsh (Tables 8, 9). The seeds of these species are considerably smaller, which may facilitate dispersal over a broader area. These forbs are now present up to 520 m away from the main tidal creek.

Table 8. Number of plots with *Salicornia or Suaeda* sp. by year.

1997	2000	2002	2004	2006	2008
2	1	17	41	27	43

Table 9. Furthest distance upslope (m) from main tidal creek that *Salicornia/Suaeda* spp. have been recorded.

	1997	2000	2002	2004	2006	2008	Total distance upslope (m)
tr1	40	-	200	320	260	520	480
tr2	-	-	20	260	240	360	360
tr3	-	-	120	160	120	120	120
tr4	-	-	-	40	40	280	280
tr5	-	-	20	200	-	280	280
tr6	-	-	-	40	-	280	280

Phragmites continues to show the same trends that are described in previous reports. Marsh-wide, *Phragmites* has not declined (Figure 3). In fact, there are slightly more plots with *Phragmites* in them now than there were in 1998 (prior to restoration), although less than in 2002-2006. However, as mentioned previously, it is primarily the distribution of the *Phragmites* population that is vastly different from pre-restoration conditions (Figure 4). In this regard, *Phragmites* continues to shift upslope, towards the upland boundary and away from the main tidal creek (Figures 6, 7, Table 10). This movement is highly correlated with salinity gradients along these transects (Figure 3). *Phragmites* tends to thrive at salinities between ~10 and 25 ppt (Smith et al., in press) – levels that are high enough to kill salt intolerant herbaceous and shrub species but well within their tolerance range. This species has the ability to spread rapidly by means of horizontal stems, from which sprout new shoots, that creep into areas opened by the death of salt intolerant communities. However *Phragmites* has largely disappeared or been severely reduced in plots with salinities > 25 ppt, which have also increased in frequency (Table 2).

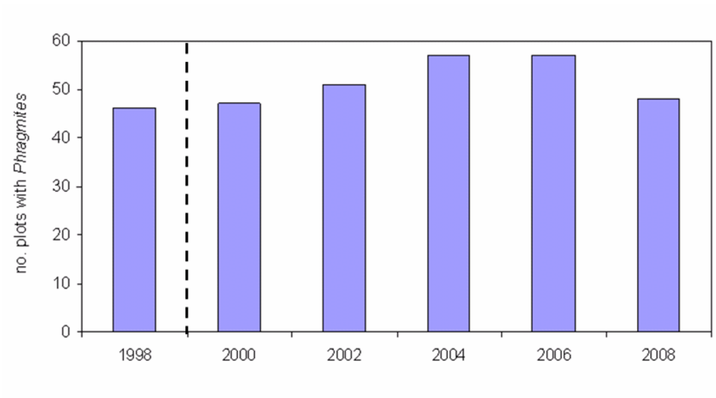

Figure 5. Total number of plots with *Phragmites* by year (dotted line divides pre- vs. post-restoration).

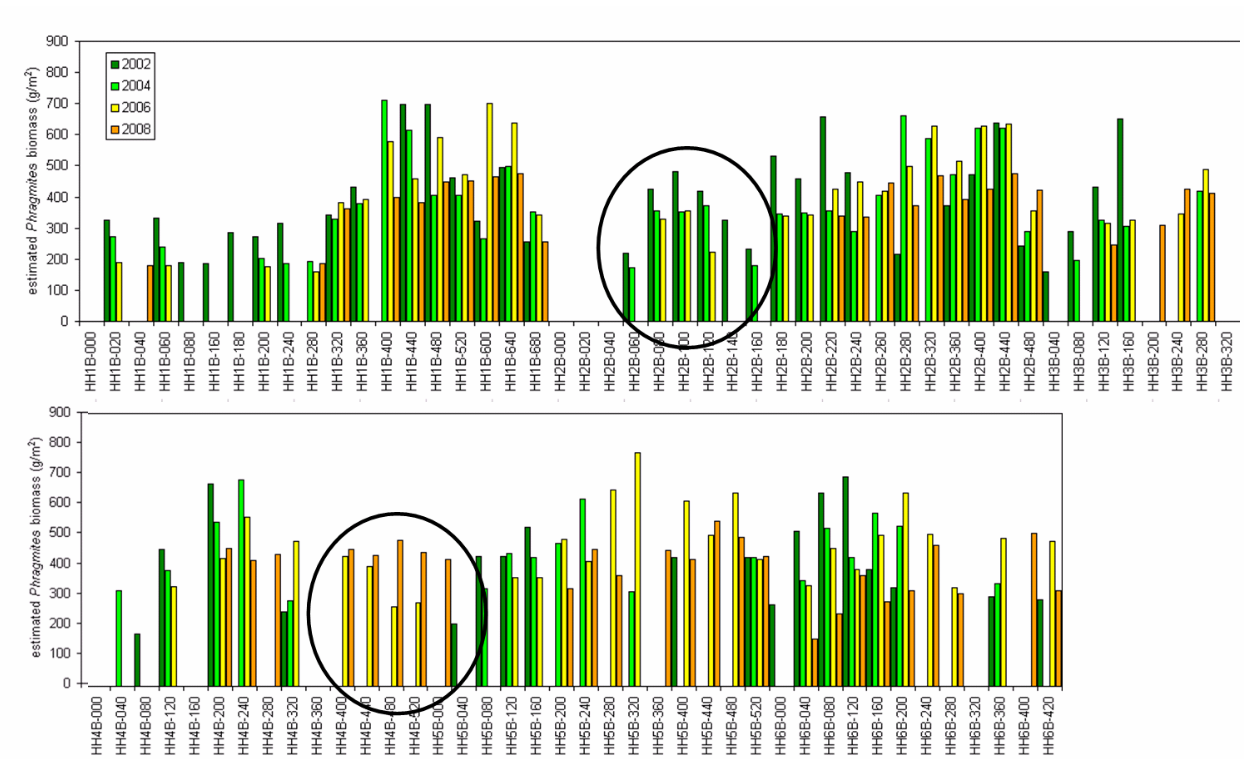

Figure 6. *Phragmites* biomass along transects 1-6 estimated from maximum stem heights and stem densities (circled area in top graph is an example where *Phragmites* has recently disappeared; circled area in bottom graph is where Phragmites has recently appeared).

Table 10. Distance (m) from tidal creek to plot where *Phragmites* first appears along transects (i.e., position of "front edge" of *Phragmites*).

	1997	2008	Total displcaement upslope (m)
TR1*	20	280	260
TR2	20	180	160
TR3	40	120	80
TR4	40	200	160
TR5	40	200	160
TR6	1	40	40

Aerial image analysis is particularly informative with respect to assessing the extent of change in salt marsh vegetation patterns across the entire landscape. Aerial photography was available for 2005 (MassGIS) and 2007 (Google Earth). The seaward edge of *Phragmites*, which consists of dead and stunted live stems entangled with lines of wrack material, is visually distinct and, therefore, its position is relatively easy to follow through time. Figure 7 below shows the landward retreat of the *Phragmites* edge. This movement creates more open space for native halophyte establishment and growth.

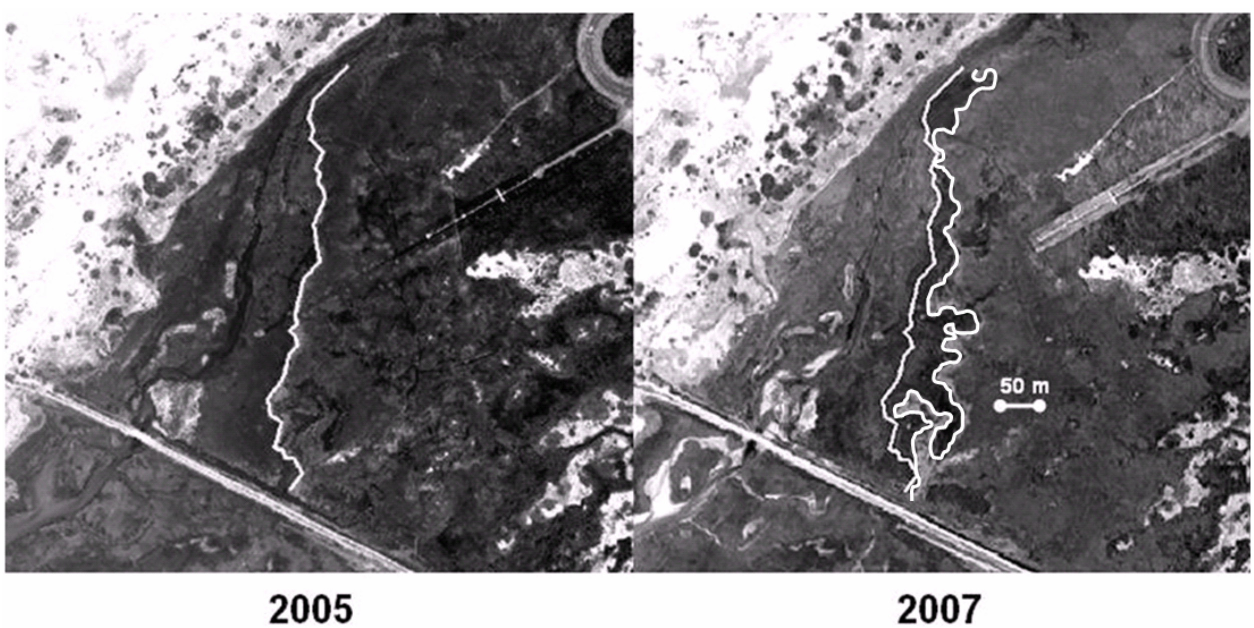

Figure 7. Position shift of the front edge (white line) of *Phragmites* population on the restricted side of Hatches Harbor in 2005 (left) vs. 2007 (right).

As *Phragmites* migrates upslope it does so, in part, by opportunistically invading areas of recently killed salt-intolerant vegetation. Horizontal stems grow out across these new openings, from which new shoots sprout. Soon thereafter, the space fills in with vigorous *Phragmites* since there is no inter-specific competition in the area and salinities are still relatively low (Figure 8).

Figure 8. Photos of salt-killed *Phragmites* at the seaward edge of population (left) and invasion of *Phragmites* into a salt-killed shrub zone at the landward edge of the population (right).

Conclusions

Tidal restoration in Hatches Harbor has allowed for the recovery of many acres of salt marsh habitat since 1998 (Smith et al., in press). The following general trends have been documented since the onset of restoration and are continuing today. They are:

- decline in freshwater (salt –intolerant) taxa
- landward migration of *Phragmites*
- landward expansion of native halophyte communities

Although no changes have been made to the physical structure through which tidal exchange occurs (i.e., the gated culverts), the system continues to change physically and ecologically. Some changes are the result of species finally succumbing to the prolonged salinity and hydrologic changes that have occurred since restoration began. In turn, the continuing degradation of salt-killed plant communities alters the dynamics of seed dispersal, sediment transport, and surface water flow across the marsh, which facilitates more change. Thus, salt marsh expansion is expected to continue well into the future.

Future monitoring and management plans for Hatches Harbor

- Vegetation will continue to be monitored in all permanent plots every 2 years. *Phragmites* monitoring will continue on an annual basis, as will porewater salinity, and tide heights.

- Unfortunately the Seashore has not been able to conduct a burn in Hatches Harbor during the last two years as was originally planned. The intent of burning would be to eliminate some of the standing dead woody material and *Phragmites* biomass that constitute a significant barrier to halophyte seed dispersal and surface water flow. Despite our inability to accomplish this task to date, we will continue to advocate for its use as a management tool for this system.

- A web page has been created for this project and can be found at:

  http://www.nps.gov/caco/naturescience/hatches-harbor-tidal-restoration-project.htm

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II. NEKTON (FISH AND DECAPOD CRUSTACEANS)

Kimberly Lellis-Dibble

Introduction

Tidal restoration has been ongoing at Hatches Harbor since spring 1999. Since nekton respond rapidly to ecological changes, especially to changes in hydrology, they can be used as biological indicators. Changes in nekton abundance, density, length, and species composition reflect perturbations in multiple ecosystem processes that provide insight into ecosystem alterations post- tidal restoration. Nekton also respond to changes in food web dynamics from the bottom up or the top down, making them important species to monitor in restored/restoring salt marshes (e.g. changes in primary producer populations influence transfer of organic materials up the food chain (bottom up); or alternately, changes in predators will influence trophic level dynamics within food webs (top down) (Raposa and Roman 2001a,b).

Yearly nekton sampling of species composition, abundance, length, and density has taken place at Hatches Harbor since 2003. The nekton community has responded favorably to the reintroduction of tidal flow into the restricted section of the Hatches Harbor marsh. Nekton community structure in creeks and pools has shifted to more closely resemble the unrestricted portion of the system seaward of the dike (Portnoy *et al*. 2003; Portnoy *et al*. 2005). The following is a report on nekton abundance, density, and species composition at Hatches Harbor using additional data collected in 2008.

Methods

Sample Design

Sampling was attempted twice during the 2008 season at sixty stations distributed randomly in creeks and pools in the restricted and unrestricted sites in Hatches Harbor. However, because many stations had no standing water in 2008, only 48 stations were sampled in July and 12 stations were sampled in September (Table 1). Use of lift nets in the restricted portion of the marsh in 2008 could not be completed due to a lack of suitable sampling conditions (either dry or flooded over the bank during low tide).

Table 1. Number of sample stations by type and habitat strata. The first number is for number of stations sampled in June, second is for September 2008.

	Creek (throw trap)	Pool	Marsh Surface	Creek (lift net)
Restricted	14/4	12/0	No Data	No Data
Unrestricted	12/8	10/0	No data	No Data

Throw traps yield repeatable and quantifiable measures of nekton density (Rozas and Minello 1997) and have been used to sample nekton at this site since 2003. After each throw, the trap contents were emptied and each specimen was identified, counted, and the first 15 of any one species was measured for length (in millimeters). Environmental data was also collected at each site and included measurements of salinity, water temperature, and dissolved oxygen (Table 2).

Sampling Period

Nekton was only sampled during low tide when all of the water left the marsh surface and the throw traps could be effectively deployed. Sampling was conducted on two 2-day events (22-23 July and 8-9 September 2008). Each sampling session was conducted over two days for several hours.

Data Analysis

For each year, we report the number of animals sampled, number of species, their relative abundance, and mean and standard deviation of nekton density. A statistical analysis using XLSTAT software (Sokal and Rohlf 1981) was *not* conducted using this data (as was done in 2003-2007). A larger effort to analyze data from multiple restoration sites (including Hatches Harbor) over multiple years is currently underway. This multivariate analysis will provide a better understanding of how Hatches Harbor has changed over the span of tidal restoration and what principal factors may be contributing the most to changes in nekton communities over time (e.g., changes in environmental factors, vegetation, hydroperiod, etc.).

Results and Discussion

Environmental Factors

Water temperature was generally cooler in the creeks (~16-19º C) than in the pools (~22-23º C). Dissolved oxygen was lowest in the restricted creeks and pools, as expected with a higher proportion of high-oxygen-demand wetland runoff. Also expectedly, salinity decreased with distance from the source of tidal water: ~32 ppt on the unrestricted side to ~28 ppt on the restricted side (Table 2).

Table 2. Environmental variables for Hatches Harbor by habitat strata and sample area for 2008.

	Unrestricted		Restricted	
	Creek	Pool	Creek	Pool
Temperature (C)	19.91 ± 1.19	23.66 ± 0.45	16.75 ± 0.21	22.60 ± 0
Salinity (ppt.)	32.05 ± 1.75	32.06 ± 0.86	27.25 ± 0.92	28.90 ± 0
Dissolved oxygen (mg/L)	7.35 ± 2.30	8.48 ± 1.27	2.80 ± 1.19	2.69 ± 0

Nekton

During the 2008 sample period, three species of fish and three species of crustaceans were collected (Table 3), with the common mummichog (*Fundulus heteroclitus*) the dominant fish species and the sand shrimp (*Crangon septemspinosa*) the dominant crustacean (Table 4). In unrestricted creeks, the sand shrimp dominated (Table 5b) which is likely due to the habitats' wide, shallow, sandy creeks that are ideal for sand shrimp. In the unrestricted pools and restricted creeks and pools, mummichogs were most common and were mostly found in sheltered areas (e.g., eroded creek banks) (Tables 5a,c,d). Tidal restoration at Hatches Harbor has allowed more sand shrimp to inhabit restricted creeks over the 2003-2008 period, as evidenced by an increase in density and number captured (Table 5a). One new species was sampled in unrestricted creeks, the cunner (*Tautogolabrus adspersus*) (Table 3). This species is common in coastal and estuarine waters.

Table 3. Species sampled at Hatches Harbor 2003 to 2008. R-restricted area of marsh; U-unrestricted area of marsh; C^1-creek habitat >1m wide; C^2-creek habitat <1m wide; P-pool habitat; MS-marsh surface habitat.

	2003				2004				2005				2006							2007				2008			
	R		U		R		U		R		U		R				U			R		U		R		U	
Species	C	P	C	P	C	P	C	P	C	P	C	P	C^1	C^2	MS	P	C	MS	P	C	P	C	P	C	P	C	P
American eel									X				X														
Green crab				X			X	X	X	X	X		X	X	X		X	X	X	X		X		X	X	X	X
Sand shrimp			X				X	X	X	X	X		X				X			X	X	X		X		X	
Sheepshead minnow	X																										
Mummichog	X	X	X	X		X	X	X	X	X	X		X	X		X	X		X	X		X		X	X	X	X
Striped killifish		X	X	X		X	X		X		X																
Atlantic silverside							X	X	X		X									X		X					
White perch									X																		
Shore shrimp	X		X																							X	
Winter flounder							X		X		X															X	
Hermit crab																						X					
Menhaden																						X					
Cunner																										X	
Total species	3	2	4	3	0	2	6	4	8	3	6	0	4	2	1	1	3	1	2	4	1	6	0	3	2	6	2

Table 4. Relative abundance (percent) of nekton by habitat strata and sample area in 2008.

	Unrestricted Creek	Restricted Creek	Unrestricted Pool	Restricted Pool
Fish	9	96	88	80
Decapod	91	4	12	20
Carcinus maenas	11	1	12	20
Crangon septemspinosa	79	3	0	0
Fundulus heteroclitus	7	96	88	80
Palaemonetes sp.	2	0	0	0
Pseudopleuronectes americanus	<1	0	0	0
Tautogolabrus adspersus	1	0	0	0

Table 5a. Mean nekton density (and standard deviation) and number of species sampled by habitat strata and sample area from 2003-2008. The number in parenthesis is the total number of nekton species sampled.

	Hatches Harbor Restricted Creek Nekton Density					
	2003	2004	2005	2006	2007	2008
TOTAL DECAPOD	0.86 ± 2.27 (6)	NO DATA	6.2 ± 9.84 (371)	0.3 ± 0.84 (10)	3.13 ± 1.94 (84)	0.17 ± 0.51 (3)
TOTAL FISH	38.93 ± 43.23 (282)		43.41 ± 56.81 (1950)	1.27 ± 2.83 (38)	7.53 ± 7.62 (185)	3.67 ± 7.50 (66)
TOTAL NEKTON	30.57 ± 26.81 (288)		27.22 ± 29.96 (2321)	0.8 ± 1.42 (48)	10.65 ± 5.67 (269)	3.83 ± 7.50 (69)
Anguilla rostrata			0.03 ± 0.18 (1)	0.07 ± 0.25 (2)		
Carcinus maenas			0.16 ± 0.58 (8)	0.3 ± 0.84 (9)	0.12 ± 0.07 (3)	0.06 ± 0.24 (1)
Crangon septemspinosa			8.95 ± 21.52 (363)	0.03 ± 0.18 (1)	3.01 ± 2.01 (81)	0.11 ± 0.47 (2)
Cyprinodon variegatus	0.14 ± 0.38 (1)					
Fundulus heteroclitus	40.14 ± 42.38 (281)		51.23 ± 59.63 (1914)	1.2 ± 2.85 (36)	7.28 ± 7.26 (179)	3.67 ± 7.50 (66)
Fundulus majalis			0.52 ± 1.75 (16)			
Menidia menidia			0.48 ± 1.91 (15)		0.5 ± 0 (6)	
Morone americana			0.03 ± 0.18 (1)			
Palaemonetes spp.	0.86 ± 2.27 (6)					
Pseudopleuronectes americanus			0.1 ± 0.3 (3)			

Table 5b. Mean nekton density (animals/m^2) in unrestricted creek area 2003-2008.

	Hatches Harbor Unrestricted Creek Nekton Density					
	2003	2004	2005	2006	2007	2008
TOTAL DECAPOD	2.63 ± 3.86 (42)	17.5 ± 24.34 (318)	12.54 ± 19.24 (528)	2.2 ± 4.93 (58)	14.39 ± 15.01 (259)	10.95 ± 27.23 (219)
TOTAL FISH	45.28 ± 102.15 (762)	2.36 ± 2.79 (40)	5.08 ± 8.15 (169)	0.64 ± 2.36 (14)	3.44 ± 1.26 (62)	1.05 ± 3.58 (21)
TOTAL NEKTON	41.96 ± 101.98 (804)	14.6 ± 16.36 (358)	12.01 ± 15.42 (697)	1.56 ± 2.75 (72)	17.83 ± 16.26 (321)	12.00 ± 27.43 (240)
Brevoortia tyrannus					0.11 ± 0 (1)	
Carcinus maenas		0.14 ± 0.32 (3)	0.45 ± 1.01 (12)	0.64 ± 1.94 (14)	0.22 ± 0 (2)	1.30 ± 4.73 (26)
Crangon septemspinosa	0.31 ± 1.01 (5)	21.14 ± 30.76 (315)	15.75 ± 24.04 (516)	2 ± 5.35 (44)		9.45 ± 23.69 (189)
Fundulus heteroclitus	46.19 ± 101.91 (739)	2.55 ± 4.16 (28)	3.91 ± 6.72 (86)	0.64 ± 2.36 (14)	2.83 ± 1.81 (51)	0.86 ± 2.92 (17)
Fundulus majalis	1.44 ± 3.22 (23)	0.18 ± 0.4 (3)	0.95 ± 4.05 (21)			
Gasterosteus aculeatus						
Menidia menidia		0.45 ± 1.21 (5)	2.68 ± 11.03 (59)		0.56 ± 0.63 (10)	
Pagurus longicarpus					0.22 ± 0 (2)	
Palaemonetes spp.	2.31 ± 3.93 (37)					0.20 ± 0.89 (4)
Pseudopleuronectes americanus		0.36 ± 1.21 (4)	0.14 ± 0.47 (3)			0.05 ± 0.22 (1)
Tautogolabrus adspersus`						0.15 ± 0.67 (3)

Table 5c. Mean nekton density (animals/m^2) in restricted pools 2003-2008.

	Hatches Harbor Restricted Pool Nekton Density					
	2003	2004	2005	2006	2007	2008
TOTAL DECAPOD			3 ± 4.5 (43)		0.33 ± 0 (0)	0.08 ± 0.29 (1)
TOTAL FISH	46.92 ± 40.25 (341)	8 ± 9.17 (24)	25.69 ± 28.24 (207)	5.6 ± 11.53 (84)		0.33 ± 0.78 (4)
TOTAL NEKTON	46.92 ± 40.25 (341)	8 ± 9.17 (24)	18.51 ± 21.13 (250)	4.8 ± 10.65 (84)	0.33 ± 0 (1)	0.42 ± 1.00 (5)
Carcinus maenas			0.13 ± 0.35 (1)			0.08 ± 0.29 (1)
Crangon septemspinosa			3.63 ± 5.26 (42)		0.33 ± 0 (1)	
Fundulus heteroclitus	56.33 ± 49.36 (338)	2 ± 3.46 (6)	25.69 ± 28.24 (207)	5.6 ± 11.53 (84)		0.33 ± 0.78 (4)
Fundulus majalis	0.5 ± 1.22 (3)	6 ± 10.39 (18)				

Table 5d. Mean nekton density (animals/m^2) in unrestricted pools 2003-2008.

	Hatches Harbor Unrestricted Pool Nekton Density					
	2003	2004	2005	2006	2007	2008
TOTAL DECAPOD	0.2 ± 0.45 (1)	0.27 ± 0.65 (4)	NO DATA	0.25 ± 0.46 (2)	NO DATA	0.50 ± 0.71 (5)
TOTAL FISH	15.4 ± 34.44 (154)	40.18 ± 61.96 (442)		36.38 ± 45.83 (291)		3.80 ± 6.20 (38)
TOTAL NEKTON	10.33 ± 23.11 (155)	40.23 ± 61.92 (446)		24.38 ± 23.91 (293)		4.30 ± 6.60 (43)
Carcinus maenas	0.2 ± 0.45 (1)	0.27 ± 0.65 (3)		0.25 ± 0.46 (2)		0.50 ± 0.71 (5)
Crangon septemspinosa		0.09 ± 0.3 (1)				
Fundulus heteroclitus	30.6 ± 68.42 (153)	40 ± 62.08 (440)		36.38 ± 45.83 (291)		3.80 ± 6.20 (38)
Fundulus majalis	0.2 ± 0.45 (1)					
Menidia menidia		0.18 ± 0.6 (2)				

There was an apparent decrease in mean total nekton density in restricted and unrestricted creeks in 2008 (Figure 1), and an increase in nekton density in restricted and unrestricted pools (Figure 2) when compared with 2007 data. However, this could be an artifact of the methods used to analyze the data from year to year. The larger multivariate analysis mentioned above will remove this potential source of error and elucidate trends in nekton species over time.

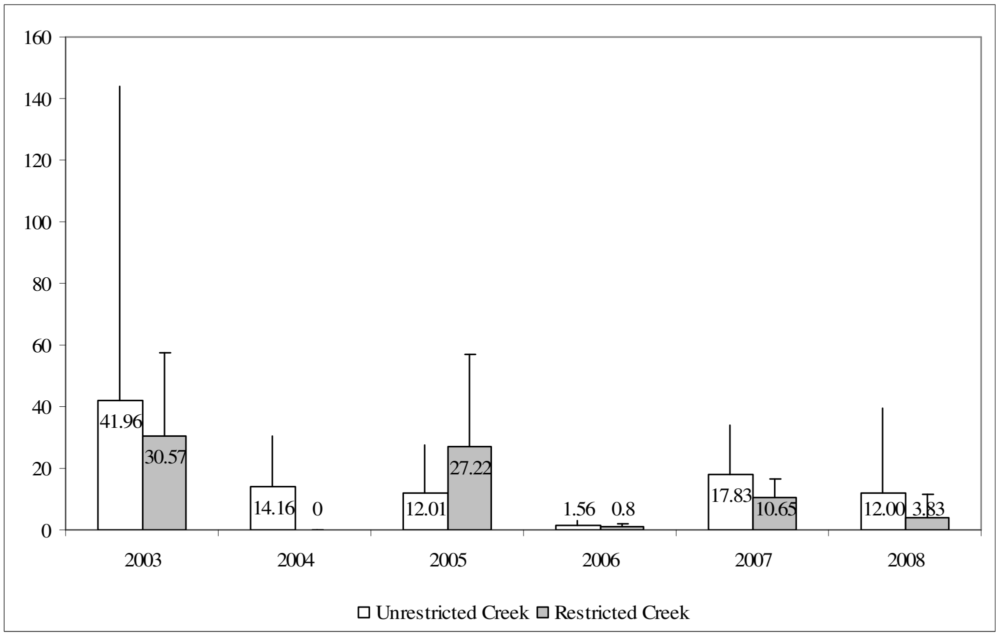

Figure 1. Mean total nekton density in creek habitat strata 2003 to 2008. Numbers on bars are density, bars indicate standard deviation.

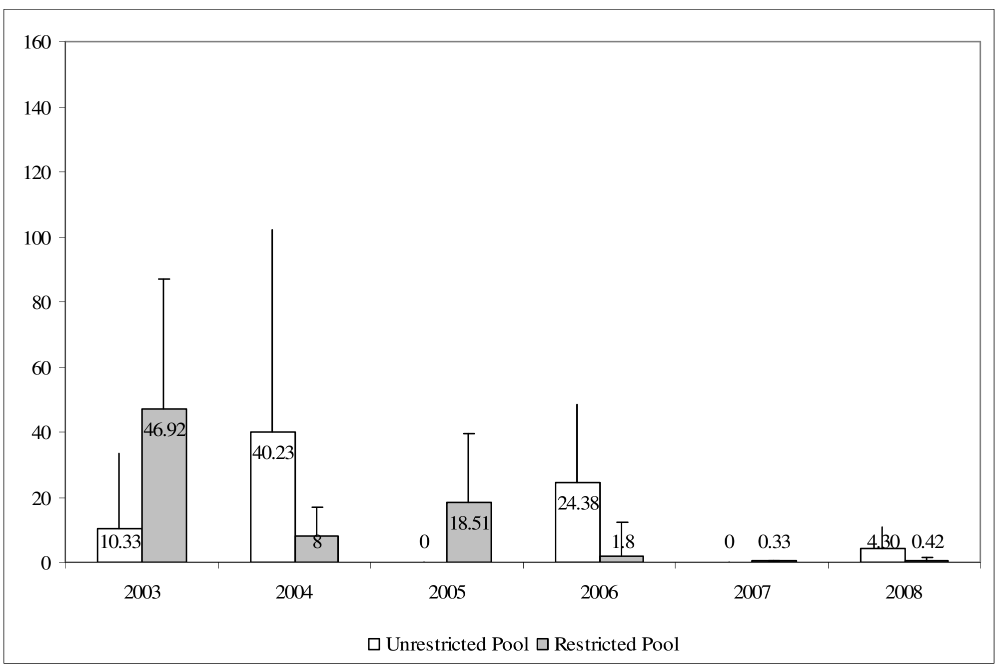

Figure 2. Mean total nekton density in pool habitat strata 2003 to 2008. Numbers on bars are density values, error bars indicate standard deviation.

Conclusions

The nekton community is responding favorably to tidal restoration and hydrologic changes that have increased suitable habitat at Hatches Harbor, as documented by this and previous annual reports. Hydrologically restored areas provide additional nursery, feeding, and reproductive areas for typical New England estuarine species, which are increasing in number and density in the Hatches Harbor restricted portion of the marsh. Results from 2003- 2008 will be used to learn more about the response of nekton to restoration and will be used to refine the monitoring protocol to make future sampling more effective. Conclusions reached based on lessons learned from implementing the nekton monitoring protocol in 2008 include:

- Increased tidal range and new creeks cut in the restricted section allow nekton greater access to essential fish habitat.
- A new species was seen in the unrestricted section of Hatches Harbor, which may begin to use the restricted area in future years.
- Several nekton species were found in the Hatches Harbor system in 2008, including mummichog, sand shrimp, green crab, shore shrimp, winter flounder, and cunner.
- Changes in creek and wetland morphology, increased suitable habitat area, and other unknown variables have resulted in decreased effectiveness of throw traps. For example, nekton may be staying on the marsh surface and not returning to the creeks at low tide, which makes sampling with throw traps ineffective.

Future work:

- Continued annual sampling in the unrestricted and restricted pools, creeks and on the marsh surface in Hatches Harbor.
- Using lift nets to sample nekton on the marsh surface. These nets were tested in the past but changing marsh hydrology and unsuitable sampling conditions rendered them ineffective. With more nekton staying on the marsh surface during low tide, lift nets may be an effective tool to sample a known area at high tide.
- A multivariate data analysis using environmental, vegetative, and nekton data from multiple restoration sites at CACO is currently underway. This analysis will discern trends in restoration success using nekton as biological indicators and suggest possible timelines for the duration of nekton monitoring post-restoration.

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